BELLCOMM, INC.
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B69 07004

SUBJECT: Advantage of the Steep Descent for Lunar Surface Visibility During Afternoon Landings - Case 310

DATE: July 1, 1969

FROM: R. Troester

NASA CR # 106461

[redacted]

Code 2B
Category 30 Pages 21

ABSTRACT

Visibility of lunar surface features during a LM descent affected by glare, as in the lunar afternoon, is generally improved by employing a steep descent trajectory rather than the present shallow approach. Two characteristics of the steep descent trajectory, its relatively steep (∿45°) look angle and its small (∿10°) pitch angle, are principally responsible for the improvement. The more nearly vertical look angle of the steep descent implies a much greater separation between the line of sight and the sun and hence a lower level of glare than in the shallow descent. The small pitch angle decreases the range of forward sun elevations in which sunlight can strike the commander's eyes directly to dazzle him or be indirectly scattered into his eyes by contamination on his window.

An analysis of the effect of scattered light on scene contrast shows that the steep descent is some twenty-fold less sensitive to this glare source than is the shallow descent. Apollo 9 and 10 mission experience indicates that scatter glare may be much less severe than previously believed. However, even if the scattering level is very high and sunlight directly strikes the commander's eyes, scene contrast in the steep descent is acceptable at all forward sun elevations between 7° and 57°. This is a much wider range of sun elevations than that afforded by the shallow descent trajectory. Since the superiority of the steep descent over the shallow descent declines with increasing sun elevation and decreasing glare, the shallow descent may be preferred where the sun is high (∿60°) or glare is absent, but even under these conditions the advantage of the shallow descent is not great.

Solar dazzle, the second component of glare, can theoretically degrade visibility to a much greater extent than will the expected amount of scatter glare. In an actual landing mission, however, dazzle should not be a factor because several methods exist to block or reduce it. Two of these, the addition of an externally mounted sunshade and the choice of an approach azimuth 30° or more to the left of the sun vector, are especially preferred since they suppress all glare effects. As has long been known, afternoon scene contrast levels with all glare blocked from the cabin are comparable to dawn landing levels, and good visibility extends over a much wider band of sun elevations in the lunar afternoon due to the absence of photometric washout from the field of view.

(NASA-CR-106461) ADVANTAGE OF THE STEEP DESCENT FOR LUNAR SURFACE VISIBILITY DURING AFTERNOON LANDINGS (Bellcomm, Inc.) 21 p

N79-71962

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MEMORANDUM FOR FILE

Introduction

A previous study (Reference 1) investigated the influence of solar glare on the visibility of lunar surface details for descent trajectories against the sun. That study assumed a trajectory profile typical of the first lunar landing mission, one in which the flight path angle is relatively shallow - roughly 15 to 18 degrees. The angle between the local horizontal and the astronaut's line of sight to the landing site, called the look angle*, also lies in this range until the very last portion of the descent when it begins to increase rapidly.

Since Reference 1 was published a class of steep descent trajectories has been defined and its properties have been studied (References 2 and 3). These trajectories are characterized by flight path angles and look angles around 45 degrees. Higate, in the "reference" steep descent trajectory adopted in Reference 2, occurs at 6,833 ft. range and 6,935 ft. altitude. The visibility phase of the descent begins at higate as the vehicle pitches up to a position 8-10 degrees back from the vertical and the landing site comes into view. After higate in this steep descent trajectory the landing site remains in view for 90 seconds compared to the 150 seconds allowed in the shallow descent.

The steep descent trajectory is especially suitable for landing missions to the Apollo science sites, because it reduces the potential landing radar update problems that can arise in the shallow descent if the approach path to the landing site lies over rough terrain. It has been suggested (e.g., in Reference 4) that long-duration missions to these sites land in the lunar afternoon in order to avoid high daytime temperatures. Additionally, landings in the lunar afternoon may provide a second opportunity to reach a given science site in the same month approximately 10 days after the morning landing. For these reasons it is of interest to extend the findings of Reference 1 to the steep descent trajectories.

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*Sometimes called the viewing angle. Refer to Figure 1 for a definition of the viewing geometry.

Analysis of Glare

The method of analysis employed in this report is the same as that of the previous study and reference should be made to it for the details not covered here. There, the principal sources of glare were identified as arising from direct solar dazzle from the sun in the astronaut's eyes and from light scattered by any films or particles deposited on the LM forward windows. The window contamination would be mostly due to the LM Reaction Control System (RCS) exhaust plume.

Both of these glare mechanisms, dazzle and scatter, act exactly like obscuring veils of light superimposed on the observed object and the background area. The contrast of an object with its background is normally defined as

$$C = \frac{\left|B_T - B_B\right|}{B_B}$$

in which B_T is the luminance (brightness) of the target object and B_B is the luminance of the background. Due to the veil of glare this contrast is reduced to C_G:

$$C_G = \frac{B_B}{B_A} \cdot C = C_R \cdot C$$

in which B_A, the adaptation luminance, is

$$B_A = B_B + B_{VD} + B_{VS}$$

B_{VD} being the "equivalent veiling luminance" of the solar dazzle and B_{VS} being the scatter luminance. The formulae for computing B_{VD} and B_{VS} are contained in Reference 1. The ratio C_R defined above is called the relative contrast and is equal to 1 if there is no glare.

Relative Importance of Dazzle and Scatter

As pointed out in Reference 1, if sunlight is allowed to strike the unprotected eye B_{VD} can be very large and seriously degrade lunar surface visibility. Nonetheless, the importance of dazzle as a constraint on an actual mission should not be overstressed as it can be avoided by a variety of hardware or operational modifications. Undoubtedly the method best suited to ensure good visibility would be to attach a lightweight external sunshade to the LM. An external sunshade could not only shield the commander's eyes as could an internal shade but it could also be mounted to block direct sunlight from the forward window, thus at once dealing with both dazzle and scatter. An internal shade would, however, be easier to adjust. A somewhat less flexible solution would be to plan for an approach azimuth some 30° or more to the left of the sun vector (as seen by the astronauts) in which case the LM forward beam would block the light. In any case, even if no pre-mission provisions were made against dazzle, the commander's automatic reflex would be to squint and avert his eyes as much as possible. He might further employ his Extravehicular Visor Assembly as a sunshade. Thus, the implicit assumption in the dazzle calculations that the eye is completely unprotected is quite conservative.

The magnitude of the other component of glare, B_{VS}, is governed primarily by the value of a parameter called the scattering coefficient, σ, the fraction of the window surface covered by scattering particles. The value of σ on a lunar landing mission is not known. On the basis of an experiment performed at MSC in 1966, it was calculated (Reference 1) that the minimum value of σ would be about .5%, while it was estimated that the maximum was unlikely to be more than 10%. Ground-based contamination experiments of this type are very difficult to correlate with actual in-flight performance, however. Reflection of the RCS exhaust plume by the vacuum chamber walls during the MSC test probably increased the window contamination, while later exposure to humid air during the optical measurements probably lowered the contaminant's scattering power.

The Apollo 9 mission was the first opportunity to observe the LM window contamination actually occurring in the space environment. It is very encouraging that the astronauts noticed no evidence of any RCS contamination on the windows during the entire 3 days of LM activities, which included a LM-active rendezvous and many firings of the RCS engines (Reference 5). The astronauts did see a few urine/water crystals on the upper docking window, but isolated macroscopic crystals, unless very numerous, will not trouble the astronauts' perception of lunar surface details. Since even a .5% σ level would have generated a scattering luminance of almost 100 ft-L (as bright as a piece of white paper under good indoor illumination) as far as 25° from the sun, this level of scattering or even a level of .1% or lower should have been noticeable for some vehicle orientation. This Apollo 9 experience and the apparently similar results of Apollo 10 should be borne in mind while interpreting the figures included in this report.

Glare Characteristics During Steep Descent

The viewing geometry for the visibility phase of the descent is portrayed in Figures 1, 2 and 3; the remaining figures, Figure 4 through Figure 9, indicate the manner in which the relative contrast and the contrast with glare of a 10° surface slope vary with a change in the parameters. Figure 1 defines the angles used in this study. Figures 2 and 3 show the angular limits for which sunlight can directly strike the commander's eye and generate dazzle (Figure 2) and the angles for which it can strike the portion of the window through which he is viewing the landing site and thus give rise to scatter (Figure 3). The monocular eye position assumed is the updated design eye position given in Reference 5 and is somewhat different from that used in Reference 1. The figures are schematic in that they do not indicate the interference of the RCS quad I and the front foot pad; they do include the shielding effect of the front beam and window overhang.

As shown in the figures, the sun will be blocked by the LM forward beam and all glare effects suppressed if the approach azimuth is greater than about 20° to the left of the sun vector as seen by the astronauts (an azimuth of 160° in the figures). Realistically, a guard band of at least 10° should be added since the astronauts are binocular, not monocular, and may move their heads so that the minimum azimuth for shielding would be about 30°. In the steep descent trajectory (pitch angle ∿10°), the figures indicate the commander's eyes will be shielded from the sun by the LM structure whenever the sun is more than 20° from the forward horizon. In the shallow descent trajectory, for which the pitch angle is about 40°, the sun is not blocked from the eye unless it is at an elevation above 50° and is not blocked from the window surface even when at the zenith.

Relative Contrast

Figures 4a and 4b are graphs of the relative contrast, C_R, as a function of sun elevation and are complementary to Figures 18, 19 and 20 of Reference 1. There the figures were plotted at a fixed look angle for various azimuths. Here they are plotted for one azimuth (180°) for various look angles in order to illustrate the advantages of the high look angles of the steep descent trajectory. Figure 4a graphs the component of the relative contrast due to dazzle glare alone, C_{RD}, and Figure 4b graphs the component due to scatter alone, C_{RS}, at both low (σ = .5%) and high (σ = 10%) scatter levels. C_R, C_{RD} and C_{RS} are related by the equation

$$\frac{1}{C_R} = \frac{1}{C_{RD}} + \frac{1}{C_{RS}} - 1.$$

As the figures indicate, the look angle has a significant effect on the amount of glare degradation, a larger look angle at a given sun elevation being better than a smaller angle because of the greater separation between the line of sight and the sun vector. Thus the steep descent trajectory will be much less sensitive to glare than the shallow approach. For instance, even at very high scatter levels it can be seen from Figure 4b that in the steep descent (look angle = 45°) contrast will be reduced by half or more (C_{RS} < .5) for sun elevations lower than 18° while in the shallow descent it is reduced to one half when the sun is still 42° from the horizon.

Contrast with Glare

Figures 4a and 4b present the glare analysis in its most generally applicable format since the relative contrast measures the degradation of the contrast of anything on the lunar surface and can be applied to rock outcrops, albedo differences and shadows as well as surface slopes. But the relative contrast is not directly useful in itself in determining the visibility of surface details. With a decrease in forward sun elevation or look angle the contrast without glare of a surface slope, for example, tends to increase at the same time as the relative contrast decreases and the result of this interaction, C_G, is not easy to predict. For this reason in the remaining figures the contrast with glare of a 10° surface slope (roughly the average slope of the wall of a normal crater) is plotted rather than relative contrast. In the first of these figures, Figure 5a, C_G is shown as a function of sun elevation at a representative point in the descent trajectory of Reference 2, just after the end of the pitch transient and 5 seconds after higate. Shown are contrast without glare, C; contrast with scatter glare, C_{GS}, at three scattering levels (σ = .5%, 1.7% and 10%); and contrast with both scatter and dazzle, C_G (σ = .5% and 10%). The dashed horizontal line at a contrast level of .07 is the lower bound of acceptable contrast for .5° obstacle visibility that was assumed in Reference 1.

The contrast levels shown in Figure 5a are gratifyingly high. Even at the highest scattering level and even if the sun strikes the commander's eye directly, contrast is above .07 for all sun elevations between 7° and 57° and in general is much higher. For comparison, a slope contrast of .07 corresponds to that seen in a shallow dawn landing approach when the sun is about 1° below the flight path. The comparison is somewhat misleading, however, since in the afternoon landing this contrast level is essentially uniform over the entire scene and photometric washout does not occur. When scattering is less (σ = .5%) and the forward sun elevation is 20° or lower, the slope contrast (C_{GS}) is equal to that seen when the sun is 3°-4° below the flight path in the dawn approach. In this range of sun elevations, crater and rock shadows are generally also important visual clues; Figure 4b indicates that shadow contrast (for which $C_G = C_R$) will remain above .5 with low scatter for sun elevations down to 4 degrees.*

In order to show the large improvement in contrast that the steep descent trajectory provides, Figure 14 of Reference 1 has been replotted as Figure 5b. It shows contrast

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*To demonstrate that the high contrast level displayed in these figures is truly a characteristic of the trajectory rather than of the particular scattering model used, a curve showing the effect of isotropic scatter on contrast is also plotted in Figure 5a (using the equation on page 35 of Reference 1). In general, real particles do not scatter isotropically; instead they tend to concentrate the scattered light along the direction of the incident beam. In a lunar descent the line of sight is always well away from the incident beam, typically 50° to 90° in a steep descent, so that the light scattered in the direction of the eye by any real particle will be less than the isotropic scatter at that angle. Hence, the curve in Figure 5a is the lower bound on C_{GS} for σ = .5%. As even this curve indicates acceptable contrast for sun elevations between 2° and 50°, the good visibility found for the steep descent is not dependent on the nature of the scattering model, especially at lower values of σ.

for shallow descents. Especially notable is the improvement in C_{GS}, that is, in contrast degraded only by scatter glare. The curve σ = .5% in the shallow descent and the curve σ = 10% in the steep descent are roughly the same, a twenty-fold decrease in scatter effect for the steep descent. The range of sun elevation and σ for which contrast is acceptable is much wider in the steep descent than in the shallow descent. Further, due to the smaller pitch angle in the steep descent the glare cutoffs occur at lower sun elevations. (The contrast jump at the lower, dazzle, cutoff angle is very evident; scatter is already so reduced at the scatter cutoff angle that the jump in contrast there is not apparent.)

If a sun shield is employed, comparison of curve C in Figures 5a and 5b reveals that in the shallow descent slope contrast levels are higher than steep descent levels above 10° sun elevation. The improvement is slight, however, and the contrasts in the steep descent against the sun compare favorably with the levels found for the shallow dawn approach.

Because Figure 5a is drawn for only one point in the steep descent trajectory, Figure 6 is included to show the changes in contrast during the entire descent from higate nearly to the hover point. Contrast is shown for several sun elevations from 10° to 55°. As expected, contrast levels hold constant during the early part of the descent and only begin to change as the look angle increases toward 90° near the hover point. The relative constancy of the curves implies that the value at higate can be used as a figure or merit for the entire descent.

The effect on contrast of changes in look angle, azimuth, and scattering level during the descent is shown in the remaining Figures 7, 8 and 9. In Figure 7 contrast is displayed as a function of look angle at 180° azimuth, for low (5°), medium (20°) and high (40°) sun elevations. For each sun elevation a curve is plotted showing the effect on contrast of low scatter, of high scatter and of both low scatter and dazzle together. In order to show the relation of contrast to look angle clearly, the glare cutoff due to the LM structure is not indicated in the curves. Thus, it should be kept in mind that for a pitch angle of 10°, for example, typical of the steep descent, dazzle is blocked for sun elevations above 18° and the scatter plus dazzle curve should be disregarded for the upper two sun elevations shown.

Figure 7 emphasizes once again the great increase in lunar surface contrast that a steep descent affords over the shallow descent at low to moderate sun elevations and high glare levels. At a 5° sun elevation, for instance, contrast levels in the steep descent are roughly 10 times higher than in the shallow descent. At high sun elevations the difference is not as impressive - the shallow descent is even marginally better above about 40° if the amount of glare is small - but the level of contrast in the steep descent remains good.

The influence of azimuth on the level of contrast is indicated in Figure 8. Curves for several sun elevations are shown, the dashed portion of each indicating what the contrast would be without glare. The figure is very similar in form to Figure 16 of Reference 1. As was also concluded for the case of the shallow descent, azimuths to the right of the sun vector (greater than 180°) offer little advantage over an approach directly against the sun. On the other hand, an azimuth of 30° to the left places the sun behind the LM forward beam and, by blocking all glare, raises contrast considerably. An exterior sunshade on the LM, of course, could provide this same protection without constraining the azimuth.

To show the variation of contrast with σ, contours of constant contrast are plotted in Figure 9 as a function of sun elevation and scattering level. The scattering coefficient σ is plotted logarithmically from .1% to 10%. Four different cases are shown: steep descent, with and without dazzle and shallow descent, with and without dazzle. Lowest contrast shown is .07, which was taken earlier as the minimum required to detect the smallest obstacle (.5°) of concern at any point during the descent. The unshaded area within these bounds, then, defines the region of acceptable visibility for landings against the sun. It is clearly much larger for the steep descent trajectory than for the shallow descent.

Summary

Steep descent trajectories have two characteristics that ensure their superiority over shallow descents for visual lunar surface inspection under glare conditions: a smaller pitch angle and a steeper look angle. The smaller pitch angle lowers the glare cutoff angles and decreases the range of sun elevations for which glare is a problem. The steeper look angle increases the separation between the line of sight and the sun vector, thus diminishing the sensitivity of contrast to scatter glare roughly by a factor of 20. Dazzle glare is not reduced as much as is scatter glare but would probably not be a factor in an actual landing mission since it can be blocked by exterior or interior sunshades or could at least be reduced by astronaut action in the absence of other means of shielding. The superiority of the steep descent decreases with increasing sun elevation, and for a very high sun (∿60°) the shallow descent might be marginally preferable, although surface contrast in a steep descent remains acceptable from 7° to 57° sun elevation even for very high scatter levels. In view of the lack of LM window contamination reported on Apollo 9 and 10, it may be feasible to use a shallow descent trajectory for an afternoon lunar landing, especially if dazzle glare is blocked. If scatter glare is also blocked (preferably with an external sunshade) both the steep and the shallow descent provide excellent scene contrast, the shallow descent being fractionally superior at sun elevations above 10 degrees.

Robert Troester

2013-RT-srb R. Troester

Attachments:

References

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2. Heap, F. and Mummert, V. S., "LM Descent Profiles with Steep Final Approach Phases - Case 310", Bellcomm Memorandum for File B69 03055, March 17, 1969.

3. McNeely, J. T., "Evaluation of Steep Final Approach Phase Lunar Descent Trajectories", MSC Internal Note 69-FM-63, March 17, 1969.

4. Hamza, V., "Lunar Exploration under Earthshine Illumination - Case 340", Bellcomm Memorandum for File, B69 04017, April 4, 1969.

5. Heffron, W. G., Saxton, J. A. and Sennewald, P. F. "Apollo 9 Crew Debriefing; MSC March 22-24 - Case 320", Bellcomm Memorandum for File, B69 04086, April 23, 1969.

6. "CSM/LM Spacecraft Operational Data Book", Vol. II LM Data Book Revision 1, 15 March 1969, NASA MSC SNA-8-D-027 (II) REV 1.

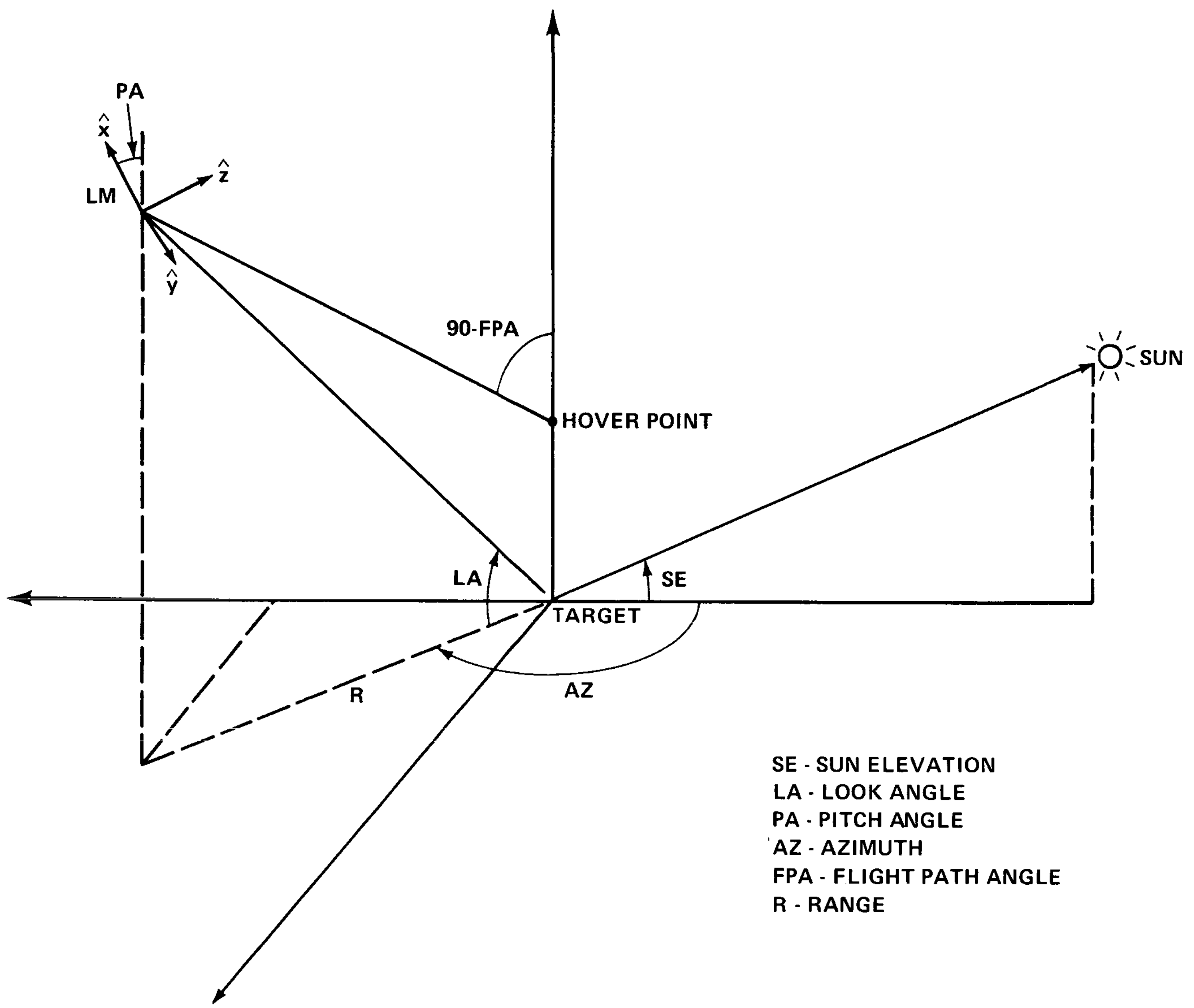

FIGURE 1 - DEFINITION OF DESCENT GEOMETRY

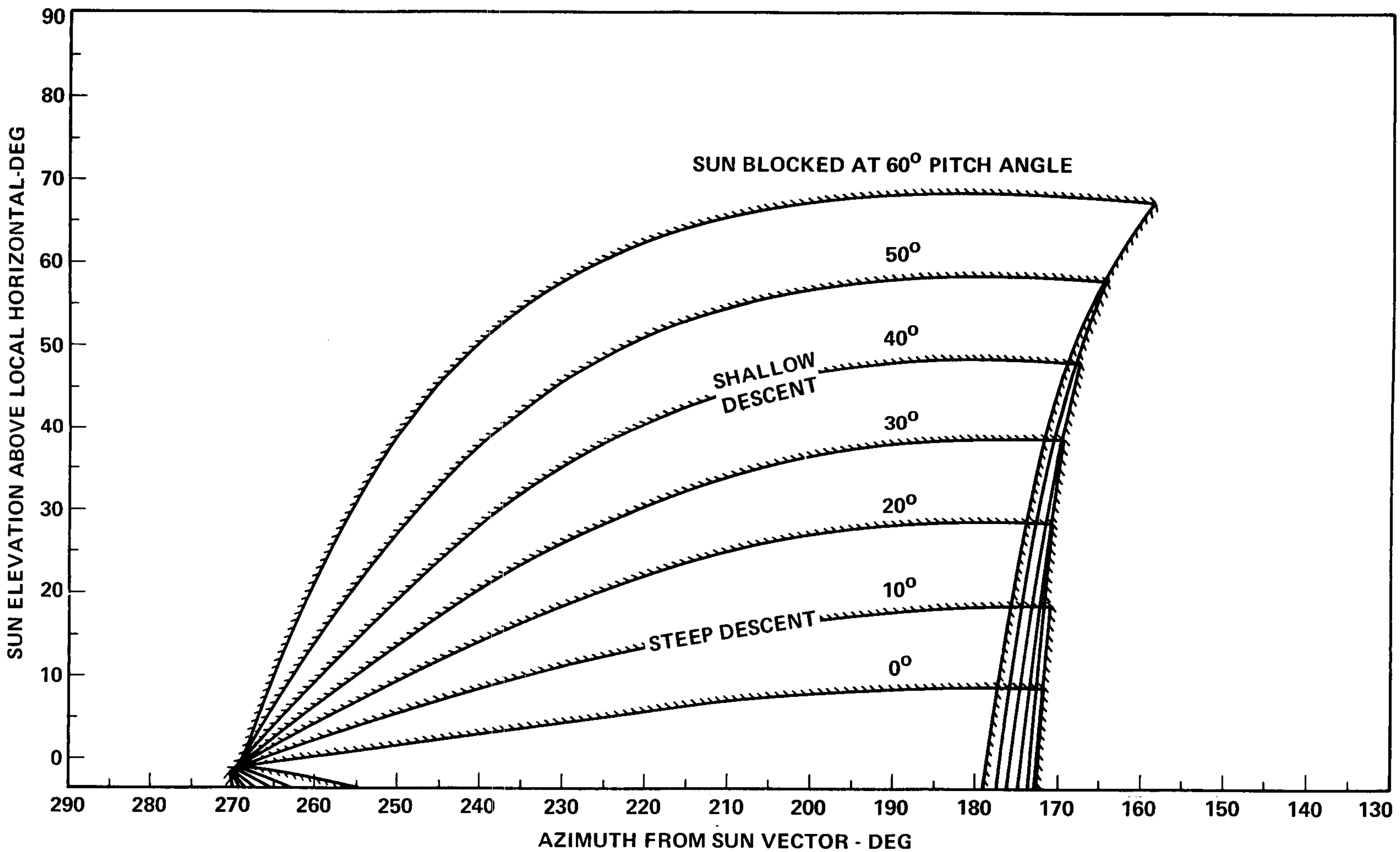

FIGURE 2 - ANGLES FOR WHICH THE SUN SHINES IN THE COMMANDER'S EYE DURING DESCENT

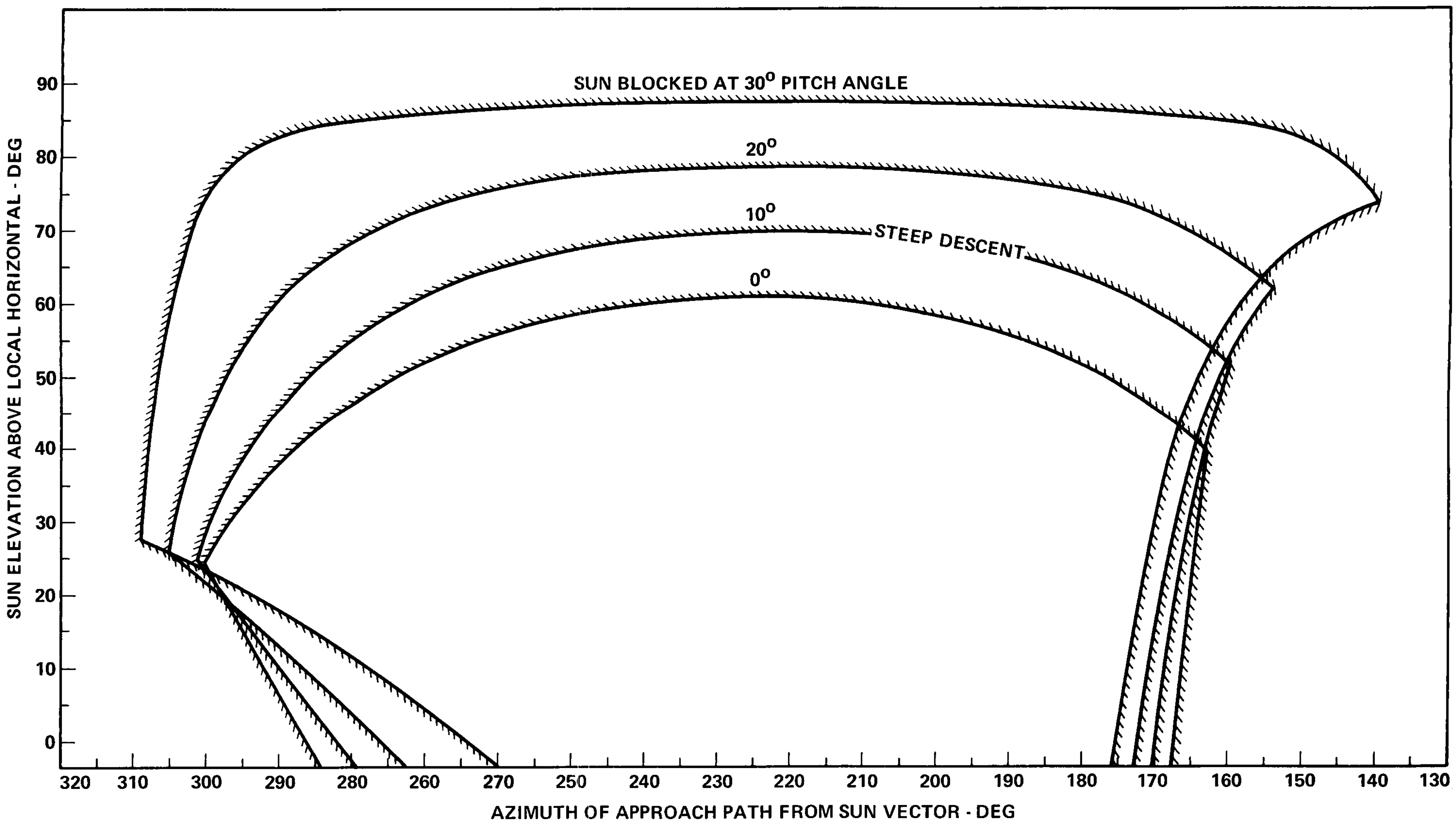

FIGURE 3 - ANGLES FOR WHICH SCATTERED SUNLIGHT MAY OBSCURE THE COMMANDER'S VIEW OF THE LANDING SITE AT A 45° LOOK ANGLE

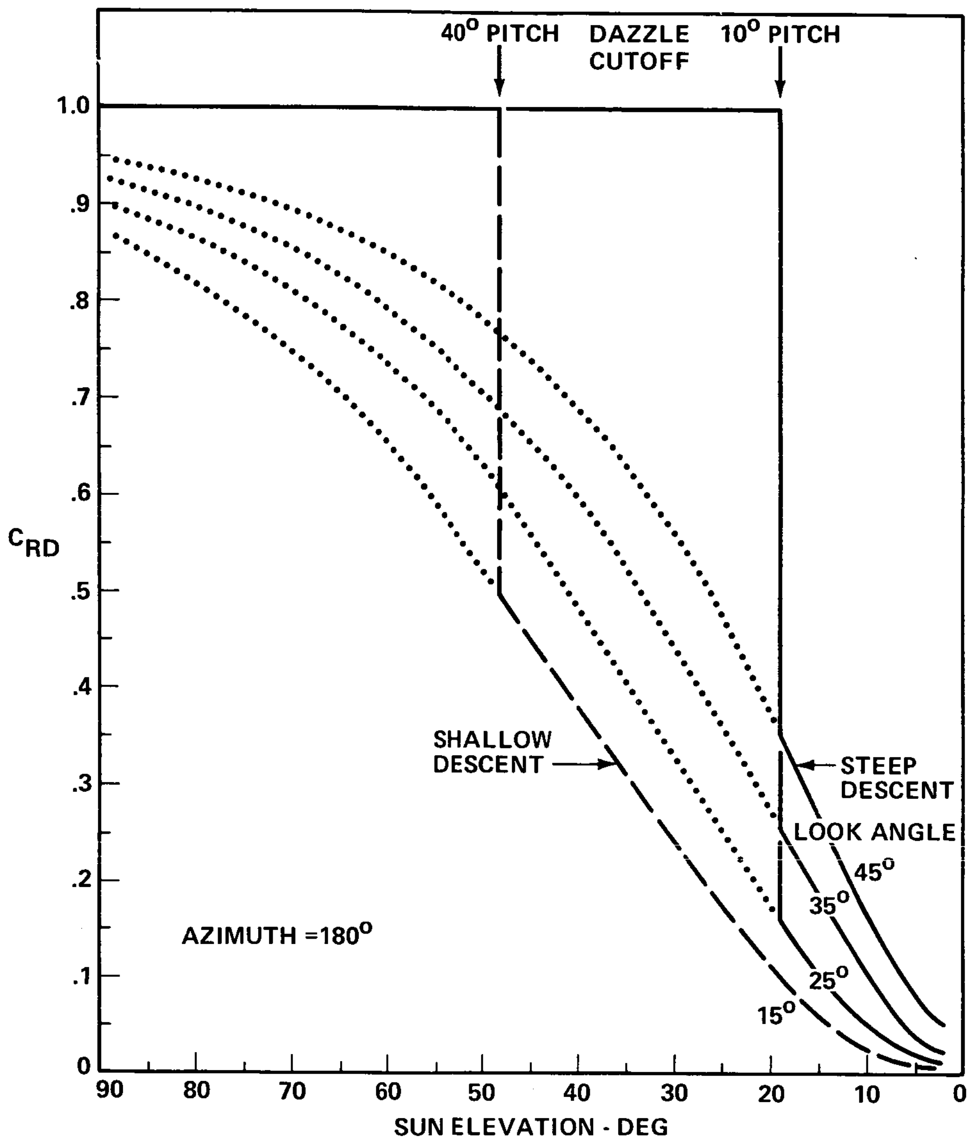

FIGURE 4a - RELATIVE CONTRAST (DAZZLE) C_{RD} AS A FUNCTION OF SUN ELEVATION

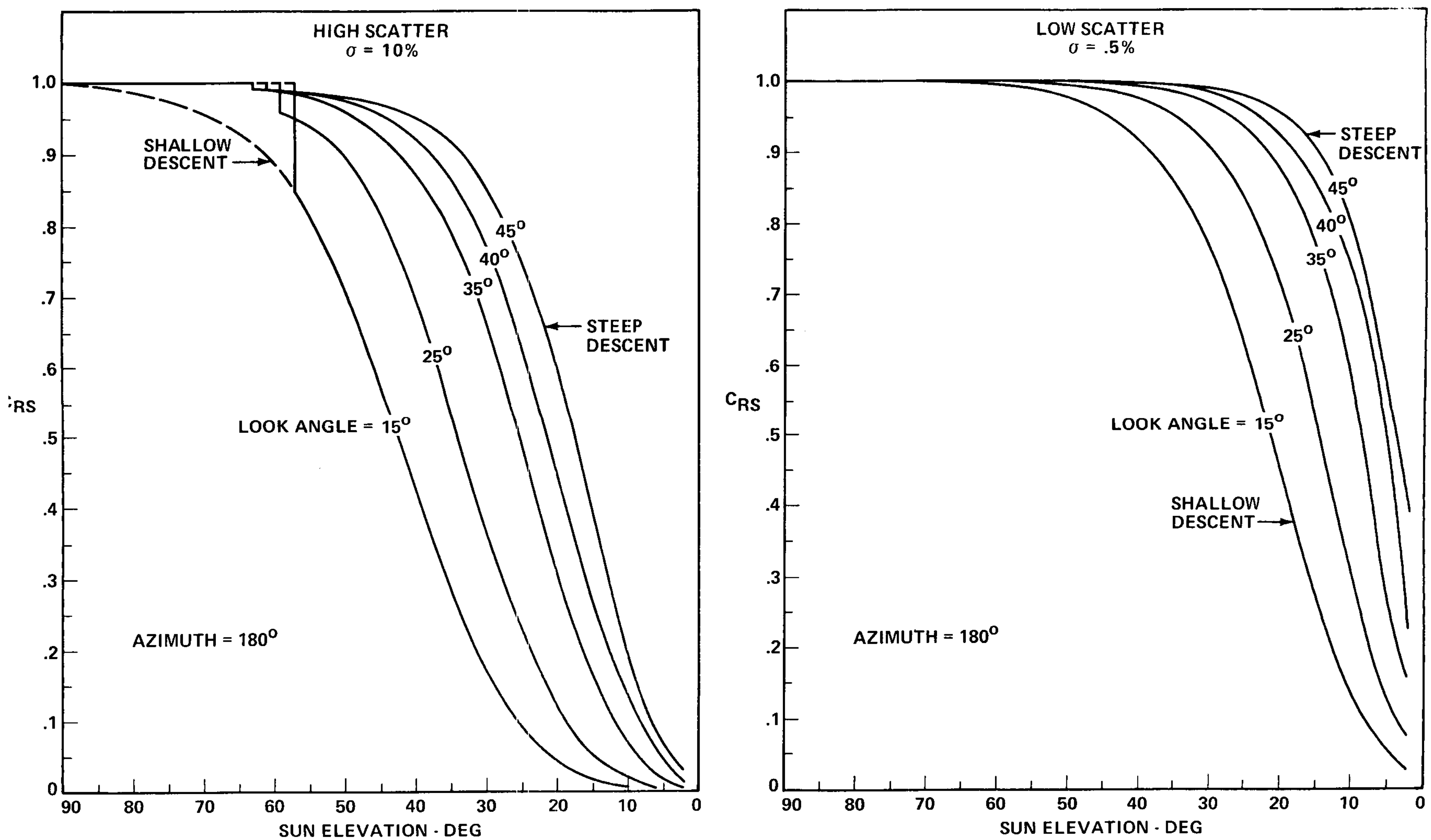

FIGURE 4b - RELATIVE CONTRAST (SCATTER) C_{RS} AS A FUNCTION OF SUN ELEVATION AT HIGH AND LOW SCATTER LEVELS

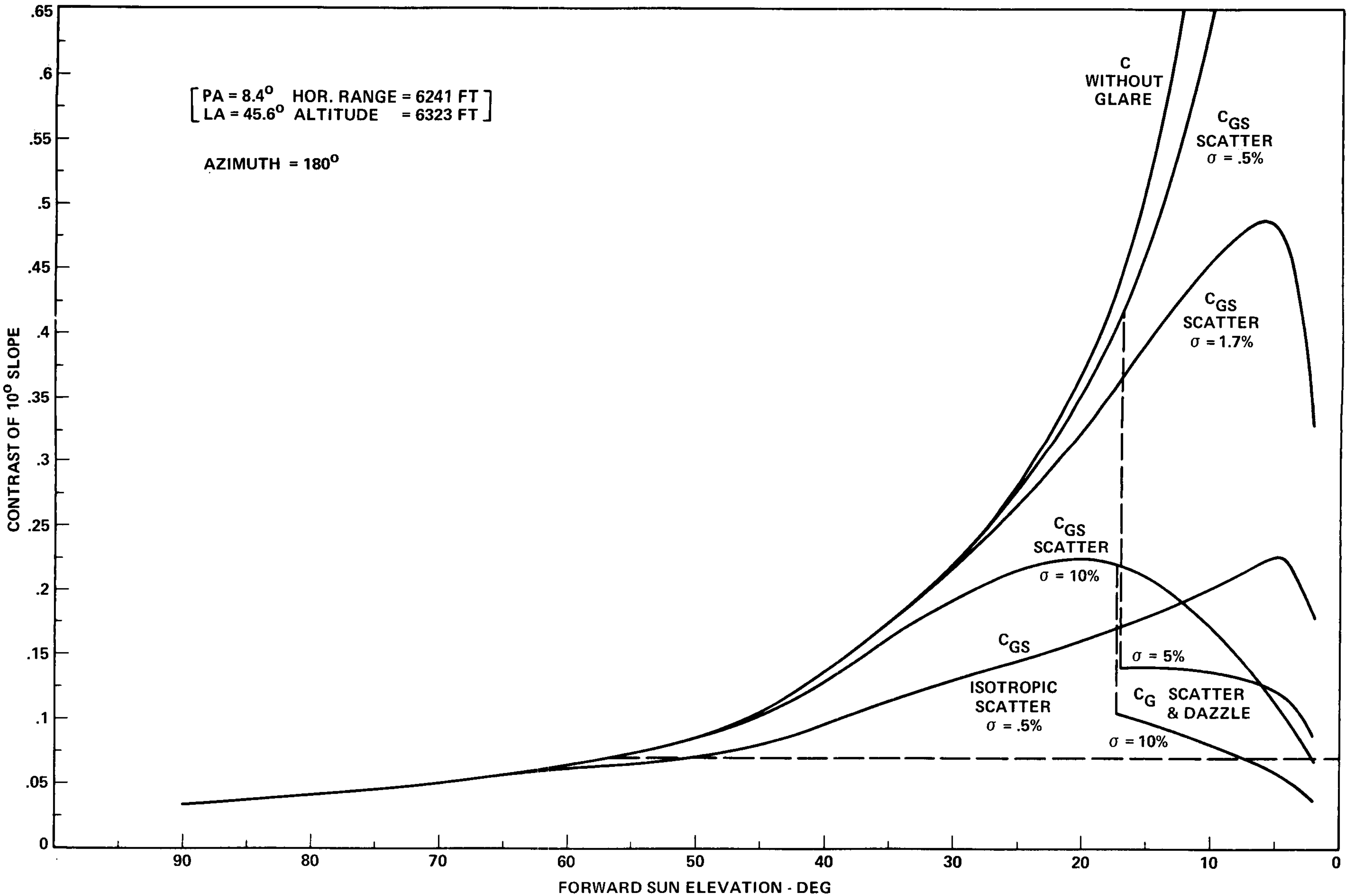

FIGURE 5a - SURFACE CONTRAST IN A STEEP DESCENT TRAJECTORY 5 SECONDS AFTER HIGATE (TYPICAL OF THE MAJOR PORTION OF THE DESCENT)

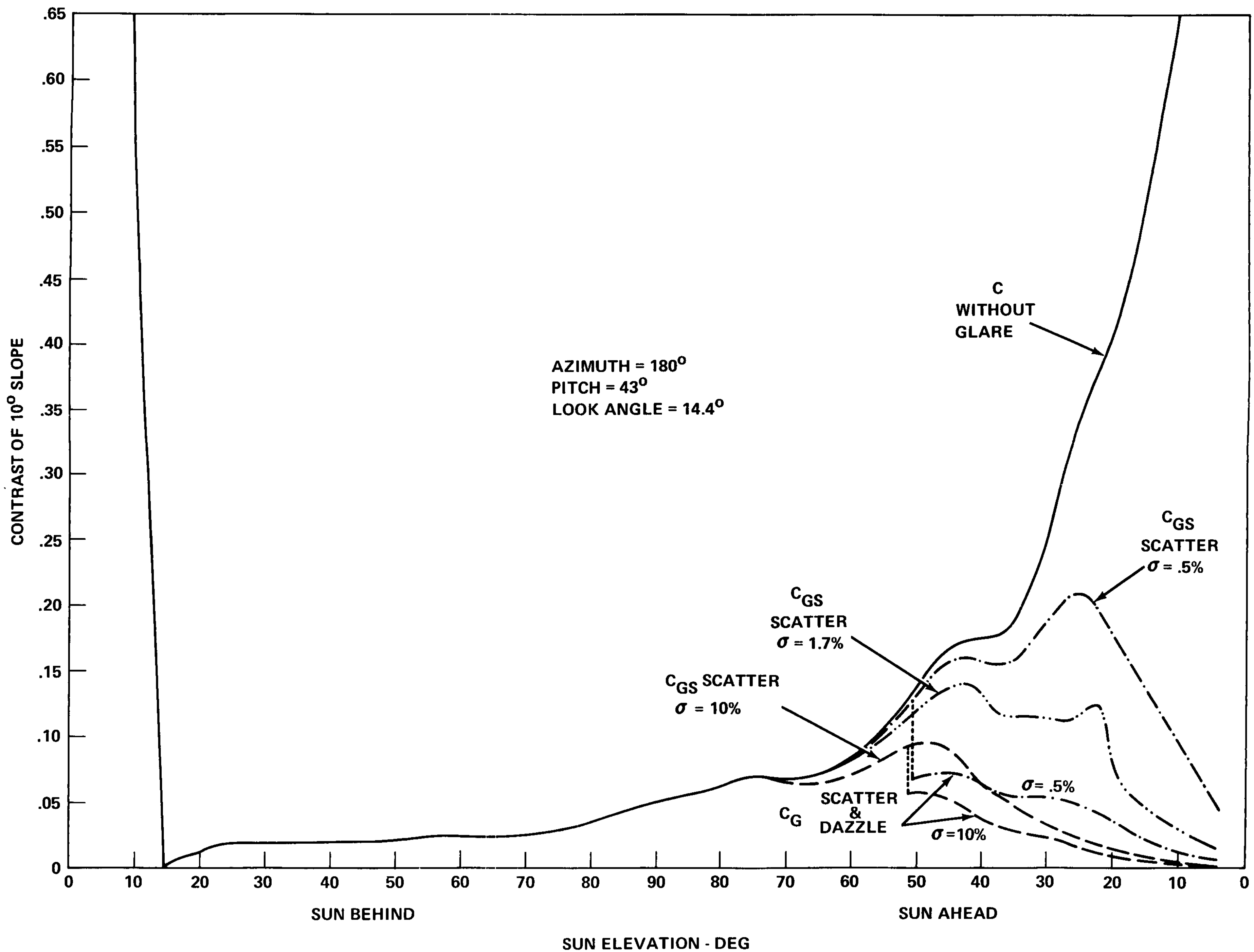

FIGURE 5b - SURFACE CONTRAST IN A TYPICAL SHALLOW DESCENT TRAJECTORY

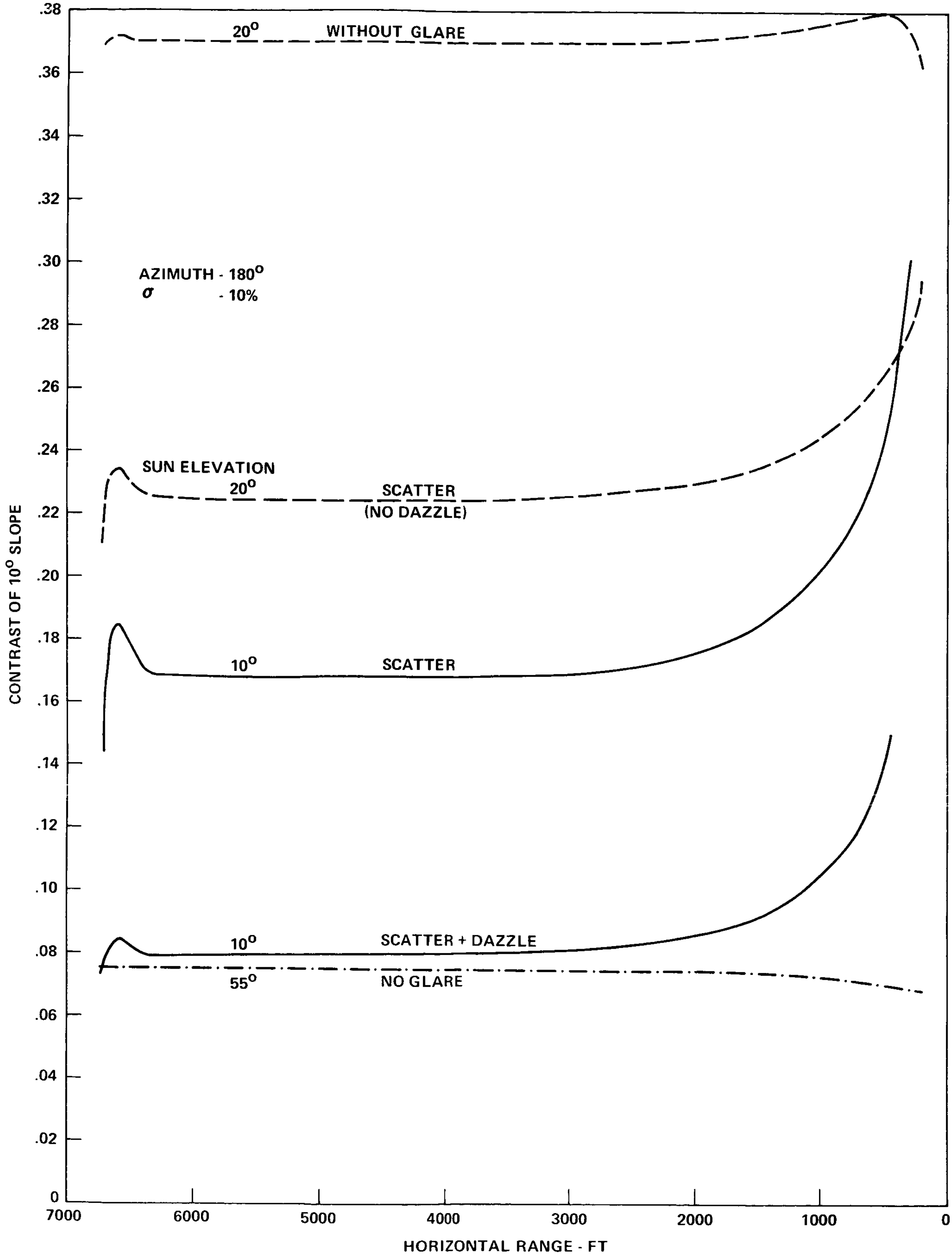

FIGURE 6 - CONTRAST AS A FUNCTION OF RANGE DURING A STEEP DESCENT

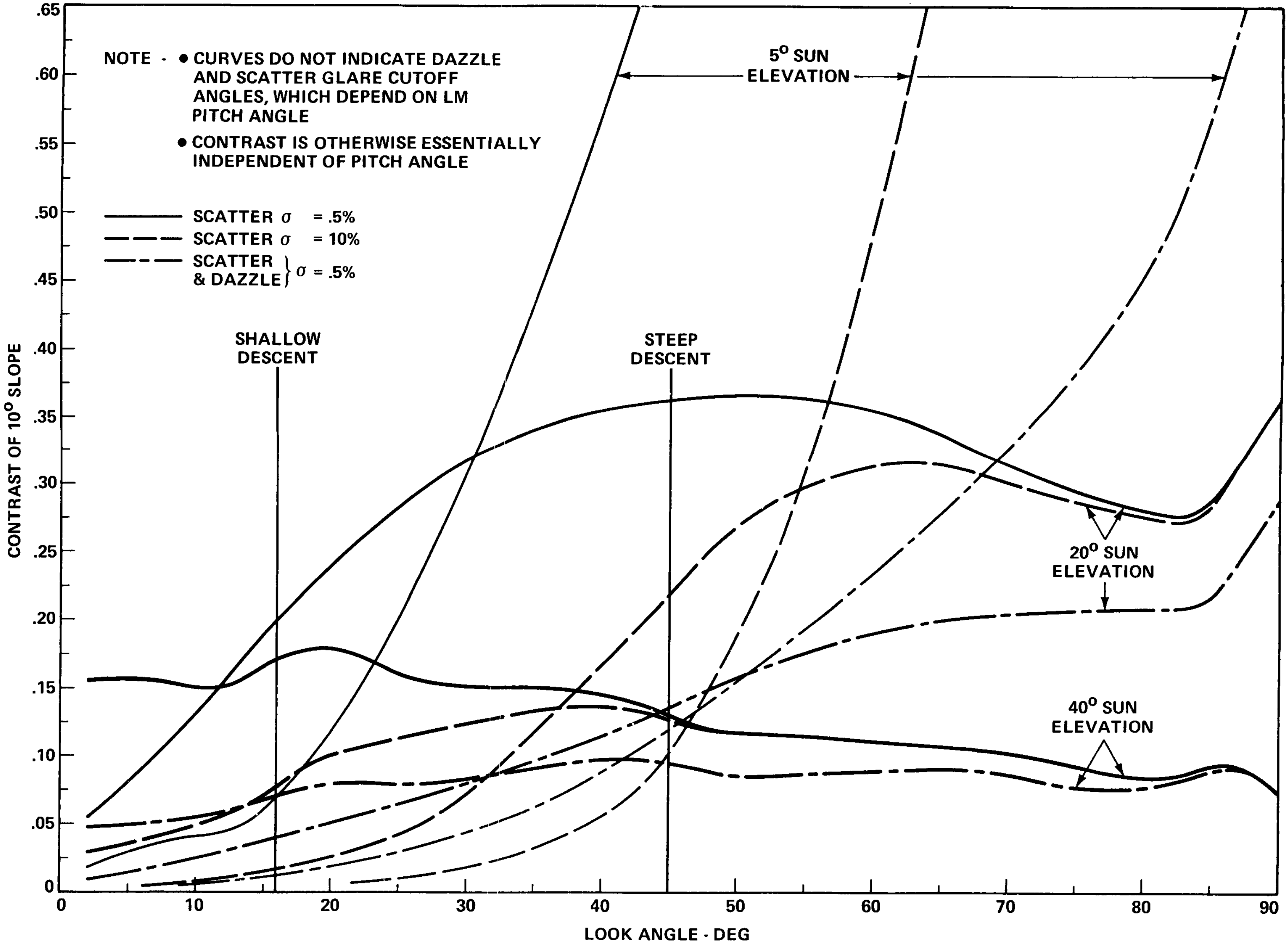

FIGURE 7 - CONTRAST AS A FUNCTION OF LOOK ANGLE AT 180° AZIMUTH

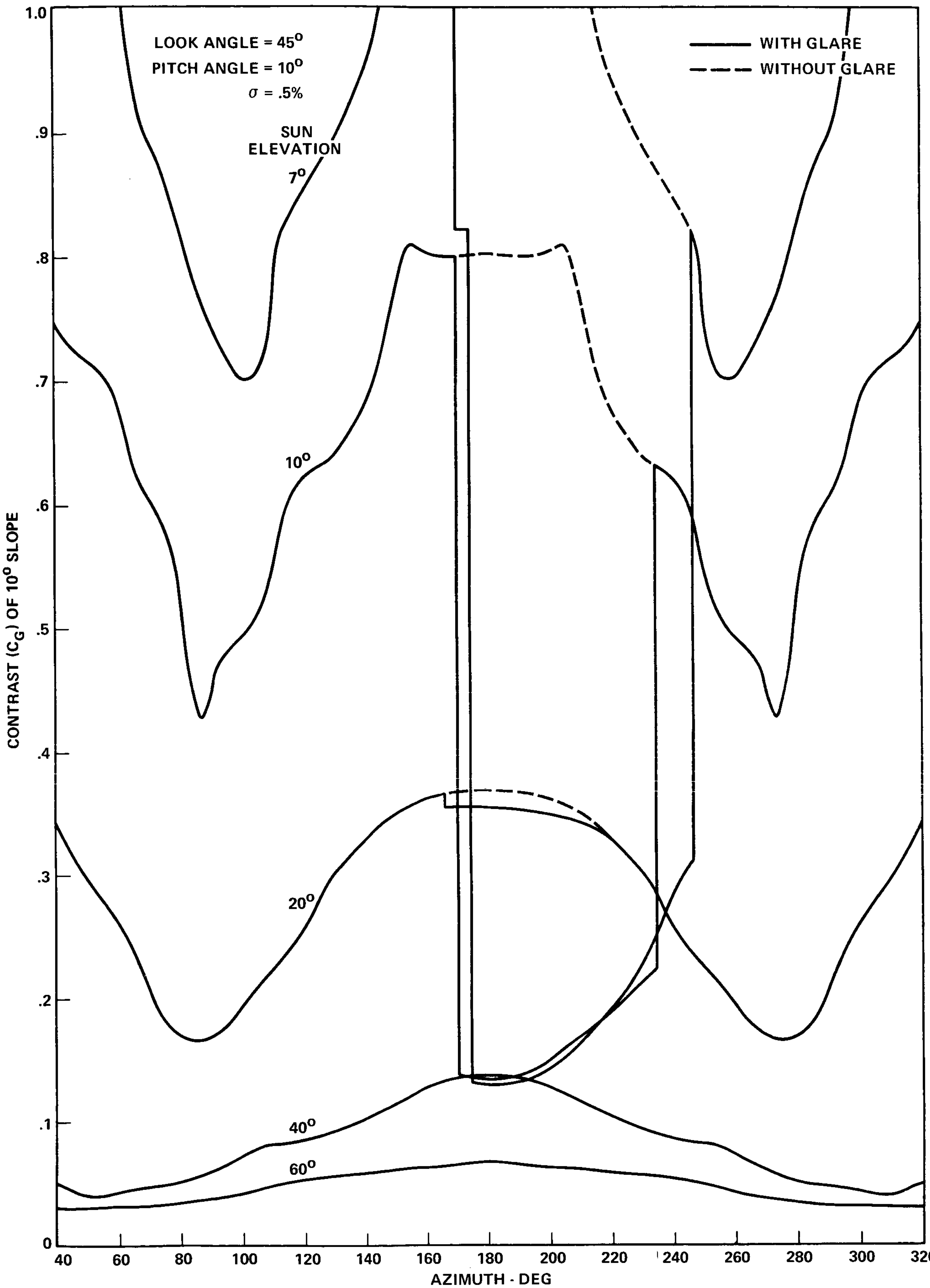

FIGURE 8 - CONTRAST WITH DAZZLE AND LOW SCATTER AS A FUNCTION OF AZIMUTH

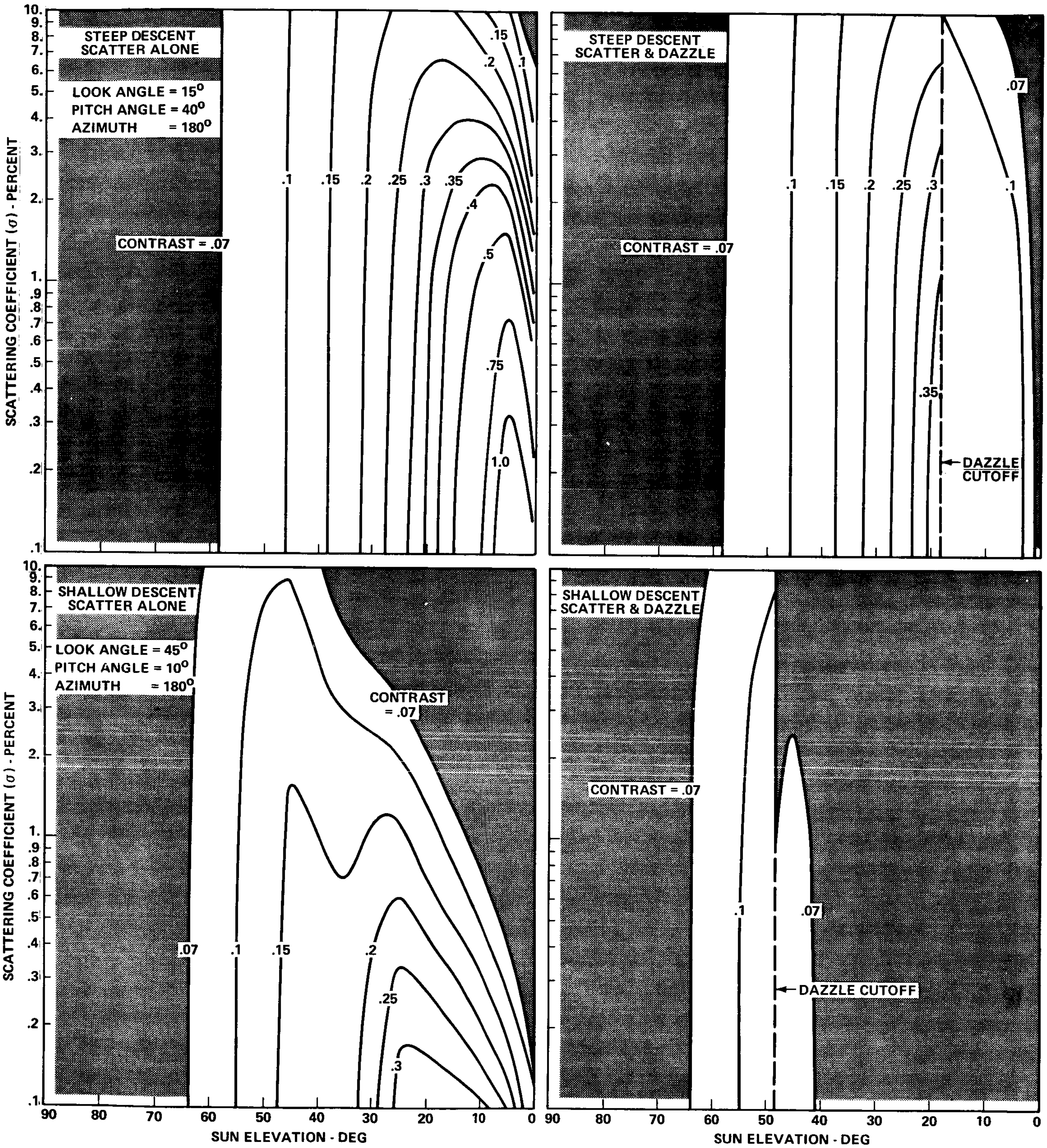

FIGURE 9 - CONTOURS OF EQUAL CONTRAST AS A FUNCTION OF SUN ELEVATION AND SCATTERING LEVEL